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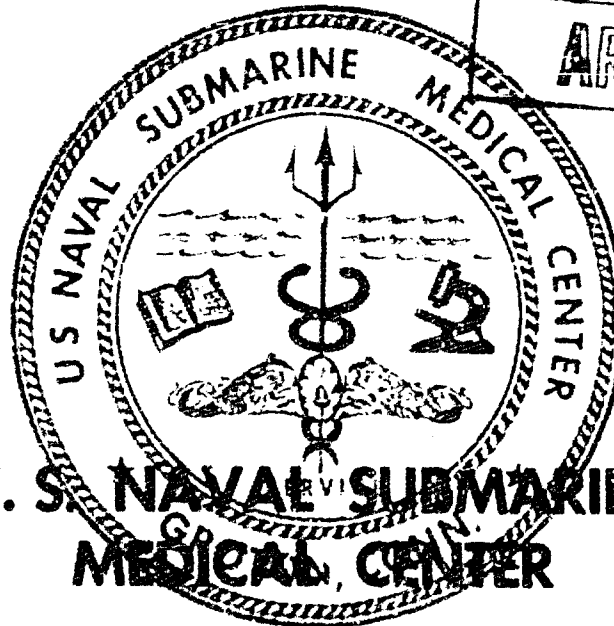
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**U. S. NAVAL SUBMARINE
MEDICAL CENTER**

Submarine Base, Groton, Conn.

REPORT NUMBER NO. 469

**OXYGEN BREATHING EFFECTS UPON NIGHT VISION
THRESHOLDS**

by

**Paul R. Kent
CDR MSC USN**

Bureau of Medicine and Surgery, Navy Department
Research Work-Unit MF011.99-3002.03

Released by:

C. L. Waite, CAPT MC USN
COMMANDING OFFICER
U. S. Naval Submarine Medical Center
2 February 1966

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Submarine Medical Research Laboratory

U.S. NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 469

**Bureau of Medicine and Surgery, Navy Dept.,
Research Work-Unit MF011.99-9002.03**

Approved by:

**Jack L. Kinsey
CAPT MC USN
Dir., Sub Med Res Lab**

Approved and Released by:

**Charles L. Waite
CAPT MC USN
Commanding Officer, SMC**

SUMMARY PAGE

THE PROBLEM

To assess the effect of breathing oxygen at ambient (sea level), and at elevated pressures, upon rod and cone night vision thresholds.

FINDINGS

Breathing oxygen at one atmosphere resulted in decreased rod and cone sensitivity at threshold illumination for one of five subjects. At 2.82 atmospheres pressure, two of four subjects showed decreased sensitivity. The reported sensitivity of rod and cone thresholds to blood sugar level was confirmed. The night vision thresholds of some subjects were elevated by breathing through a mask-demand valve system, apart from the effect of the inhalant.

APPLICATIONS

These findings are pertinent to diving and other operations where oxygen is used as an inhalant.

ADMINISTRATIVE INFORMATION

This investigation was undertaken as part of Bureau of Medicine and Surgery's Work Unit MF011.99-9002 - Effect of Unusual Environments on Visual Functions. The present report is No. 3 on this Work-Unit and was approved for publication on 2 February 1966.

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(May be released as of 14 May 1966)

ABSTRACT

Rod and cone night vision thresholds were measured while subjects were breathing oxygen at one atmosphere of pressure for periods of 140 minutes, and at 2.32 atmospheres for 20 minutes. The measuring device was a Hecht-Silvaer Adaptometer. One of five subjects showed elevated thresholds at one atmosphere, and two of four at 2.32 atmospheres.

Both rod and cone thresholds trended lower (were more sensitive) after fasting subjects ingested 100 grams of glucose while breathing oxygen at one atmosphere. Breathing oxygen at one atmosphere enhanced the night vision sensitivity of one fasting subject.

Six of eight subjects showed a small decrement in night vision sensitivity while breathing compressed air through a mask-demand valve system, as compared to free breathing of environmental air. The inspiratory resistance of the mask-demand valve system was found to be equivalent to 1.5 cm. of water, when measured with a water manometer.

OXYGEN BREATHING EFFECTS UPON NIGHT VISION THRESHOLDS

INTRODUCTION

Because of current and projected underwater and space projects, there is much interest in the physiological consequences of breathing oxygen for prolonged periods and under various conditions. The effect upon visual function is one area of interest. There are two major aspects to this concern: One is the effect upon vision in the broad sense, with its implications for effective functioning of the individual; the other is as a sensitive indicator of physiological stress. The experiments here reported, comparing the effects upon night vision of breathing oxygen and of breathing air, are concerned almost entirely with the latter aspect.

It has been known for years that variations in the oxygen concentration of the inspired air, and its partial pressure, can influence visual function. Beginning with Wilmer and Berens⁽¹⁾ in 1918, several investigators have shown, for instance, that hypoxia decreases the ability of the retinal rods to detect dim light, and the reduction is roughly proportional to the degree of hypoxia. The case for hyperoxia and its effect is not as clear-cut. Behnke, Forbes, and Motley⁽²⁾ reported a severe contraction of the visual field as one result of breathing oxygen at three atmospheres for up to four hours. There is disagreement concerning the effect of hyperoxia upon vision for less severe exposures. Herlocher *et al*⁽³⁾ reported no change in the dark adaptation curves of four subjects during a thirty-day exposure to nearly pure oxygen at a total pressure of 258 mm Hg. Miller⁽⁴⁾ found no effect upon the photopic visual fields and peripheral and central acuities of six subjects breathing 100%

oxygen through a mask at one atmosphere pressure for periods up to four hours. Critz *et al*⁽⁵⁾, in a double blind experiment, reported that subjects exposed to 100% oxygen for six hours at one atmosphere, had decreased dark adaptive ability when compared to other subjects breathing lesser concentrations. In contrast, Sheard⁽⁶⁾ found that night vision sensitivity was enhanced slightly by breathing oxygen at ground level in comparison to air. Ground level, however, was 1000 feet during his experiments.

Noel⁽⁷⁾, in experiments with rabbits, reported severe attenuation or disappearance of the electroretinogram (ERG) after prolonged exposure to oxygen at one atmosphere. He also noted that increased CO₂ concentration had about the same effect upon the ERG with the following important differences: The CO₂ concentration must be very high; the effect is not cumulative; and recovery is much faster than with oxygen toxicity.

One of the most sensitive visual mechanisms is the complex one controlling dark adaptation. Because of its sensitivity, and the fact that it is relatively easily measured and scored, it was selected as an indicator of physiological stress for this investigation. There is good precedent for this, since a number of dark adaptation studies related to physiological stress are reported in the literature. In addition to those already mentioned, several others are pertinent to this investigation.

McFarland and Forbes⁽⁸⁾ in 1940, and others since, have found that rod thresholds are sensitive to blood-sugar

levels. Patek and Haig(9) reported that the administration of thyroid extract and of alpha-dinitrophenol enhanced the night vision of their subjects. Yudkin(10) reported that alcohol or benzedrine altered rod threshold levels of dark-adapted subjects. McFarland and Forbes(8) found that inhaling oxygen counteracted the depressant effect of anoxia or hypoglycemia upon dark adaptation. In general these effects were induced rapidly. For example, Yudkin(10) reported that alcohol or benzedrine lowered the rod threshold within 15 minutes of ingestion. McFarland and

Forbes, and McFarland and Evans(3, 11) found that breathing pure oxygen counteracted the depressant effect of hypoglycemia upon night vision sensitivity within five minutes. The rapid induction of threshold changes by these agents and the reported changes in caliber and color of the retinal vessels after breathing oxygen for five minutes(12,13) gave rise to the hope that subtle alterations in dark adaptation could be detected after relatively short periods of oxygen breathing. This expectation influenced the design of this experiment.

APPARATUS AND METHOD

The results relate to data obtained with the Hecht-Shlaer adaptometer, which has been described in the literature(14).

The adaptometer was equipped with a light-adapting field of high brightness (1500-2000 millilamberts) which the subject fixated for three minutes prior to beginning the test. The subject then fixated a dim red light which was located 7° temporally to the test field. The white light test field occupied a 3° solid visual angle that was exposed in flashes of 1/5 second. The brightness of the test field was controlled by filters of known density and a calibrated wedge. Each datum represents a threshold value taken during the course of dark adaptation, or upon becoming fully dark adapted when varied experimental conditions were imposed. In plotting the results, time is represented arithmetically on the abscissa and the visual threshold in log micromicrolamberts on the ordinate.

There were two series of experiments. One was concerned with the effects of mask breathing, and breathing 100% oxygen at ambient (sea level) pressure. These experiments were conducted in a large, light-tight, air-conditioned room. The other series, concerned with breathing oxygen at elevated pressures, was performed in a darkened decompression chamber (volume 292 cu. ft.).

Human volunteers were used as subjects. Their ages ranged from 25 to 35 years, except for one subject age 57. All except the 57 year old subject were qualified diving instructors who were on duty at the Escape Training Tank, U. S. Naval Submarine Base, New London, Groton, Connecticut. As such, they were accustomed to breathing gas mixtures through face masks and to

being subjected to elevated pressures. Permission to use human subjects was granted by BuPers ltr A212-MH of 20 November 1964.

All subjects were thoroughly familiarized with the equipment and procedure prior to the experiments being reported. Most had served as subjects for similar experiments, using the same apparatus, during a period of several months prior to these experiments.

Dry Aviation Breathing Oxygen, with purity ranging from 97.8% to 99%, was used for the tests. Control runs were made while breathing either room air or compressed air. Both oxygen and compressed air were inhaled through oro-nasal masks (MSA Oro-Nasal Airline Respirator with cushion face piece) fitted with demand valves. If two masks were required for alternate breathing of different gases, care was taken to insure that each fitted the subject with the same precision. Unless otherwise noted, room air breathing control runs were made while wearing oro-nasal masks disconnected from demand valves and gas containers. This was done in order to maintain similar breathing conditions for tests and control.

The testing procedure at one atmosphere was as follows: The subject was seated at the apparatus and the room was darkened. He was then light adapted and, immediately afterwards, the course of dark adaptation was plotted. Tests were made each minute during the early stages of dark adaptation, then every three minutes and, finally, at five-minute intervals during long experiments after stable thresholds had been reached. The maximum period of O₂ breathing was 2 1/3 hours. Control runs were made first, unless otherwise

noted. A post-test control run was usually made also.

Data reflecting the influence of blood sugar levels upon night vision sensitivity was obtained during some experiments. Venous blood samples were taken when appropriate. They were analyzed for blood sugars by the Somogyi-Nelson method.

Experiments in the decompression chamber were conducted as follows: After light adaptation the first series of tests delineating the course of dark adaptation was performed while the subject inhaled chamber air (equivalent to normal air at sea level pressure). After attaining a relatively stable threshold level (30 to 45 minutes of darkness) the chamber was pressurized to the equivalent of 60 feet of water (2.82 atmos. abs.) and the tests were continued. The subject then donned the oxygen mask and further measurements were made during a 15 to 20 minute period of oxygen inhalation. The mask was then disconnected from the oxygen source and the tests continued. The chamber was depressurized, and a final test series performed.

The chamber was ventilated at least once each five minutes by opening the supply and exhaust valves simultaneously for about one minute. Care was taken not to alter the pressure level within the chamber during ventilation.

It is, of course, important to relate the observed threshold effects to good estimates of oxygen intake as measured by alveolar air sampling. This was accomplished by setting up a continuous alveolar air monitoring system similar to that described by Rahn *et al*⁽¹⁵⁾. A Beckman model C oxygen analyzer was used in the system. Since it was impractical to sample by this method during an experiment, the sub-

ject was tested at a separate session. The alveolar PO_2 was monitored during 30 to 45 minutes of oxygen breathing at one atmosphere. The necessity of a tight-fitting mask was made evident by these tests, since large reductions in alveolar PO_2 occurred if the mask was not properly adjusted.

The inter-subject range was from 612 to 643 mm. Hg. and the intra-subject variation ranged to 12 mm Hg.. The same purity of oxygen supply, oronasal mask and demand valve were used during the experiment and for alveolar tests. There is no reason to suppose that the results would have been different if the testing had been done during the experiment. Alveolar PO_2 tests were not made at elevated pressures, but care was taken to fit the mask tightly to each subject.

Oxygen delivery to the subject can be better controlled when it is made the atmospheric environment. This alternative was deliberately avoided in these experiments in order to better relate the results to diving medicine and other applications where oxygen breathing masks are worn.

An infrared pupillometer was constructed in order to determine the range of pupil size variations. The principal components were an R-110C/SAR-7 Infrared Receiver (Snooperscope), infrared light source, grid with line separation of one millimeter which could be projected in the plane of the subject's cornea, and a dim red fixation light. While crude, the device did suffice for gross (within one mm) measurements of pupil size. Each measurement consisted of the average of five readings. Determinations were made during the experiments performed at one atmosphere pressure. Measurements were not made during the hyperbaric experiments. No interruption in oxygen breathing resulted from use of the device.

RESULTS

Oxygen at One Atmosphere

Figure 1 illustrates the results for the five subjects tested. The only significant threshold change involved subject PB. He showed an average threshold rise of about 0.20 of a log unit, which occurred within the first ten minutes of oxygen inhalation and remained at this level for the full two hours of testing. Oro-nasal masks were worn while breathing both room air and oxygen, although the input was not through a demand valve while breathing air. Because of the unexpected result with this subject, he was re-tested on another day using a double blind procedure. A control run, made

while breathing room air without a mask, was followed by a second series of tests during which water pumped dry cylinder air was the inhalant. This was followed by a third run using oxygen. The sequence of cylinder air and oxygen was unknown to either subject or experimenter at the time. A five minute rest period occurred while switching the mask from cylinder air to oxygen. The results appear in Fig. 2 and show the same comparative effect as with room air. He was tested twice, more on different days, resulting in four air vs oxygen threshold comparisons for subject PB. The differences varied, but the threshold for oxygen breathing was 0.10 log units or more higher than that for air on all tests but one, when the difference was negligible.

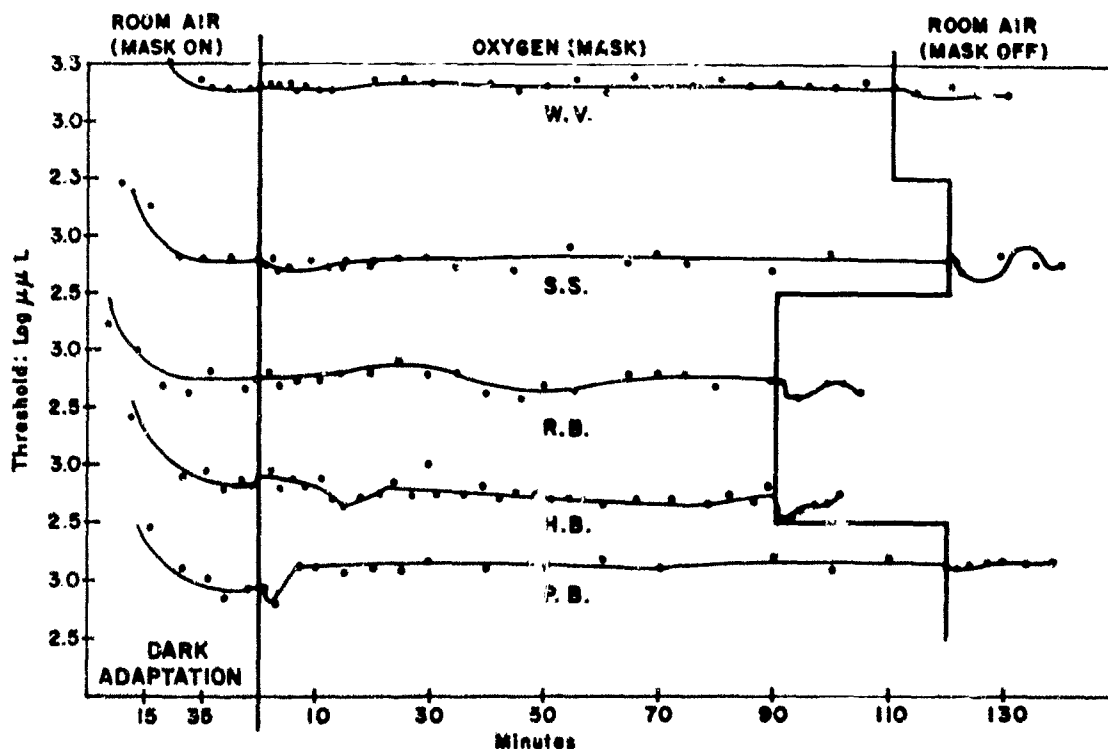


Figure 1. - Comparison of Effects of Breathing Oxygen and Room Air at One Atmosphere on the Dark-Adapted Rod Thresholds of Five Subjects. Measured with a Hecht-Shlaer Adaptometer.

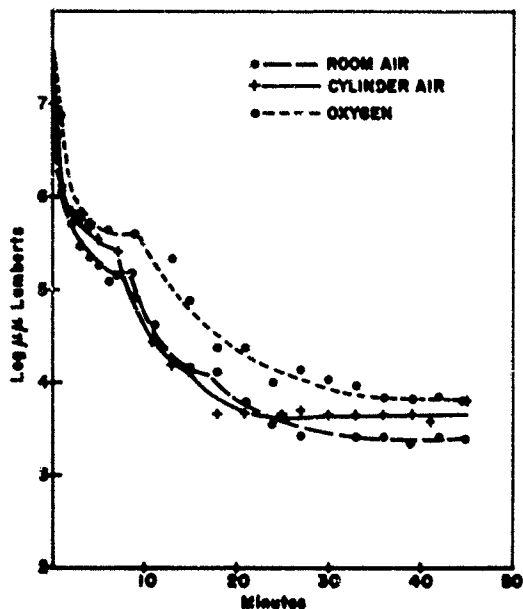


Figure 2. - Double Blind Study of One Subject, Comparing the Effect of Breathing Compressed Air and Oxygen. (Cases inhaled through similar inhalation masks and demand valves; control run, made while breathing room air without a mask, was performed first)

It is interesting to note the threshold fluctuations that usually occurred within the first ten minutes upon reverting from oxygen to room air at the end of each experiment. Typically, the threshold declined to a level below that which had prevailed at any other stage of the experiment, followed by a rebound and levelling off.

Oxygen at 2.82 Atmospheres Pressure

Four subjects were tested with the Hecht - Shlaer Adaptometer while breathing oxygen under pressure. Figure 3 illustrates the findings. Two subjects, J.S. and S.S., registered a rod threshold rise (decreased sensitivity), compared to air breathing at one atmosphere, which ranged to 0.15 log

units. Subject R.B. showed no significant threshold difference and subject W.V. exhibited an uneven lowering of the threshold (increased sensitivity) to a final level ranging to 0.25 log units below that for air breathing at one atmosphere.

The Mask Effect

Eight subjects were tested for what may be termed the mask effect, or the sum of effects upon the rod and cone scotopic thresholds due solely to breathing through an oro-nasal mask and demand valve in contrast to normal breathing of room air without a mask.

Four subjects were tested while breathing room air without a mask, followed by a second run during which dry, water-pumped compressed air was inhaled through an MSA* oro-nasal mask and demand valve. This order was reversed for the remaining four subjects. A 15 minute rest period was allowed between the two runs. The compressed air used in these experiments was tested and found to contain gaseous constituents in the proportions normal to air at one atmosphere. CO₂ content was less than 0.005%. No contaminants were detected.

A comparison of the dark adaption curves for the two test conditions showed an elevation of the rod and cone scotopic thresholds while breathing through the mask-demand valve system for six of the eight subjects. The elevations ranged from 0.10 to 0.25 log units for cone, and 0.06 to 0.36 log units for rod thresholds. Two subjects showed no rod or cone threshold difference for the two conditions. Table I lists the mean thresholds for the two conditions from the 25th to the 40th minute, and Figure 2 shows the effect for one subject.

*Mine Safety Appliance Co.

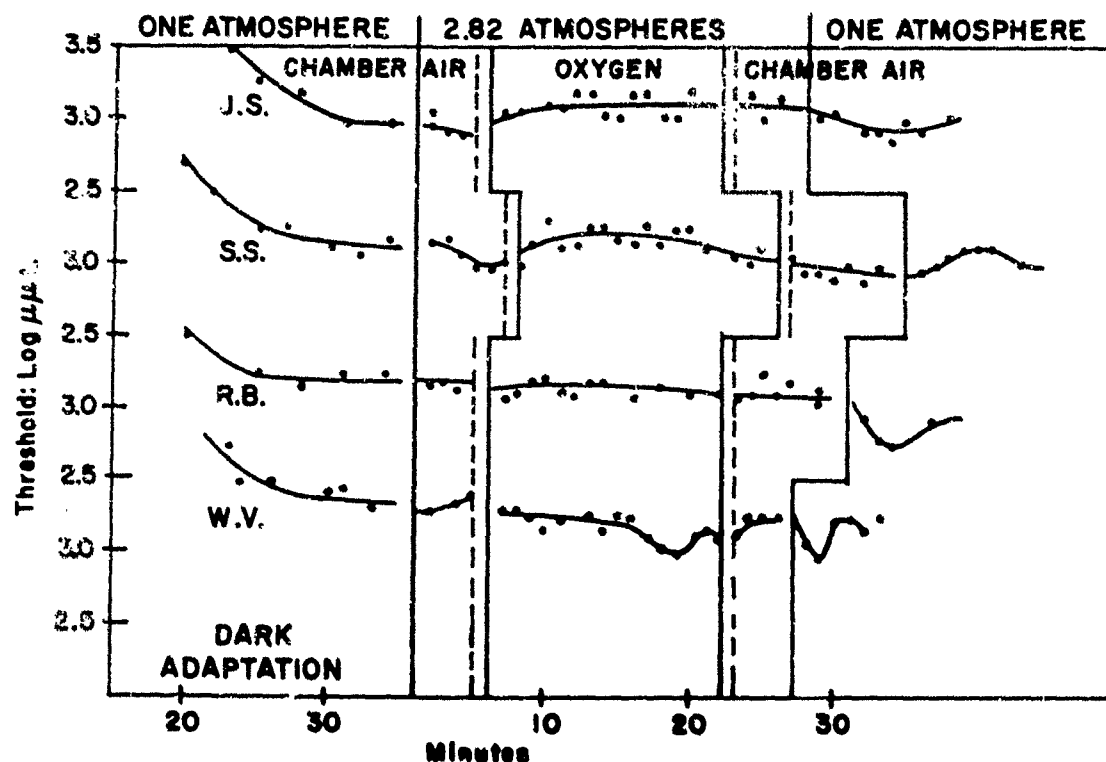


Figure 3. - Comparison of Dark-Adapted Rod Thresholds Obtained While Breathing Air at 1.00 and 2.82 Atmospheres, and Oxygen at 2.82 Atmospheres. Four subjects.

Since the distribution was unknown, the most reasonable statistic was considered to be the Wilcoxon Signed Rank (16). The null hypothesis that breathing through a mask-demand valve system has no effect upon end point cone thresholds was found to have a probability of 0.04 by this statistic.

The Effect of Blood Sugar Level

Four subjects were used in these experiments. After fasting for 12 to 14 hours, the subject was put on oxygen and a series of threshold tests made with the Hecht-Shlaer apparatus. After reaching a stable threshold level, usually after 30 to 45 minutes in darkness, the subject ingested 100 grams of glucose, followed by further testing.

Venous samples were taken before and after the glucose feeding.

Figure 4 is a composite of the results for three fasting subjects. In every such subject tested the ingestion of glucose, while breathing oxygen at one atmosphere, resulted in a gradual decline of the rod threshold over a period of 10 to 15 minutes to levels ranging from 0.15 to 0.30 log units lower than before taking glucose.

McFarland and Forbes(8), McFarland and Evans(11), and Sheard(17) have all found that breathing 100% oxygen at one atmosphere enhances the night vision sensitivity of fasting subjects. One subject in this series was tested for the effect in a double-blind experiment

Table I

Comparison of Effects upon Rod Vision Thresholds of Breathing Room Air Without a Mask and Breathing Compressed Air Through a Mask-Demand Valve System. (Each threshold value is the mean of six measurements made between the 25th and 40th minute of dark adaptation.)

Mean Threshold (Log $\mu\mu$ L) from 25th to 40th minute				
	Room Air (no mask)		Cylinder Air (mask)	
Subject	Log $\mu\mu$ L	σ	Log $\mu\mu$ L	σ
1	3.00	.023	3.36	.019
2	3.40	.063	3.66	.092
3	3.14	.14	3.20	.094
4	3.12	.067	3.12	.057
5	2.86	.205	2.97	.059
6	3.52	.144	3.58	.024
7	3.16	.07	3.16	.07
8	2.84	.06	2.92	.10
Mean	3.13		3.25	

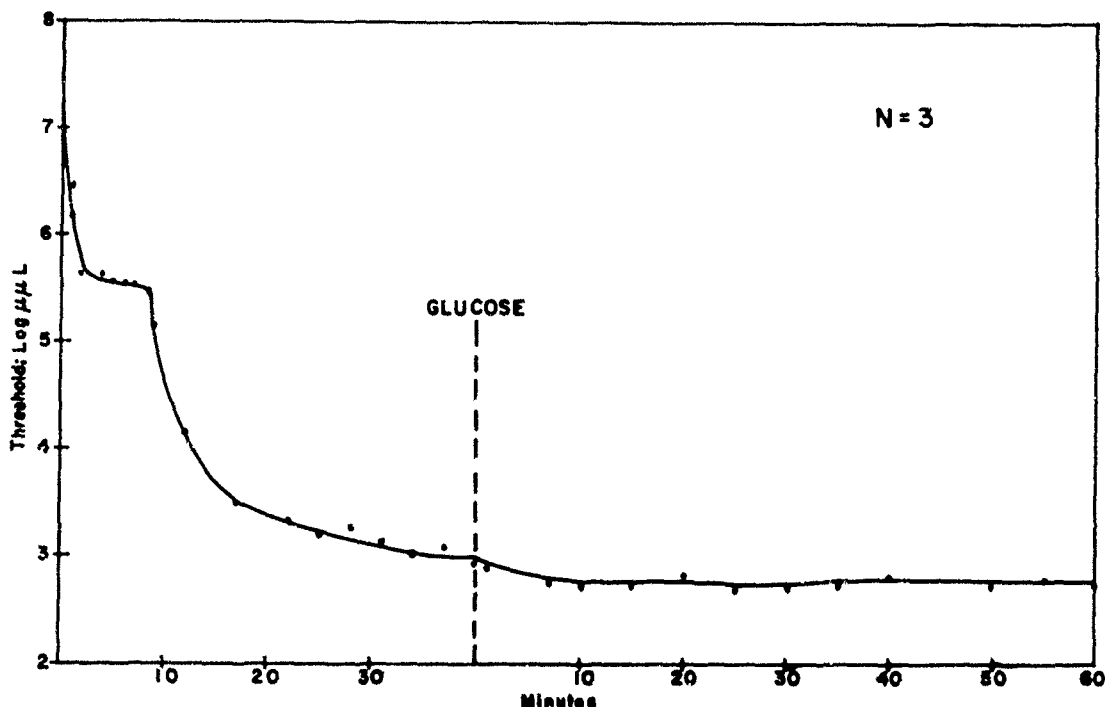


Figure 4. - Effect of Glucose Ingestion on the Dark-Adapted Rod Threshold While Breathing Near-100% Oxygen; Mean Curve of Three Fasting Subjects. (Average pre-and one hour post-glucose levels were 80mg% and 141 mg% respectively, as measured by the Somogyi-Nelson method.)

using near 100% O₂, and compressed air as a control. The cone and rod thresholds were measured on two successive days at the same hour, in the first instance after fasting for 14 hours and on the second occasion after a normal breakfast. Venous blood samples were taken each day before and after the visual tests. After fasting, both tested 76 mg% by the Somogyi-Nelson method. The comparable figures on the second day, after the meal, were 89 mg% and 86 mg%. The gas breathing sequence used on the day of fasting was: 1. Compressed air, 2. Oxygen. The double blind procedure resulted in a reversal of this sequence on the second day. A five minute break was taken in switching from one gas to the other.

Figures 5-a and 5-b illustrate the results. After the meal the average

final rod threshold (30th to 45th minute) while breathing oxygen was 0.06 log units lower than the control and after fasting 0.17 log units lower. This result, indicating that oxygen caused a greater increase in sensitivity after fasting, is consistent with previously published reports.

Pupil Size Measurements

Measurements were made on four subjects at one atmosphere pressure during the course of oxygen breathing experiments. A measure was the average of five readings. The range of variation in mean pupil diameter was no more than 0.2 mm for any subject measured during air-oxygen experiments at one atmosphere.

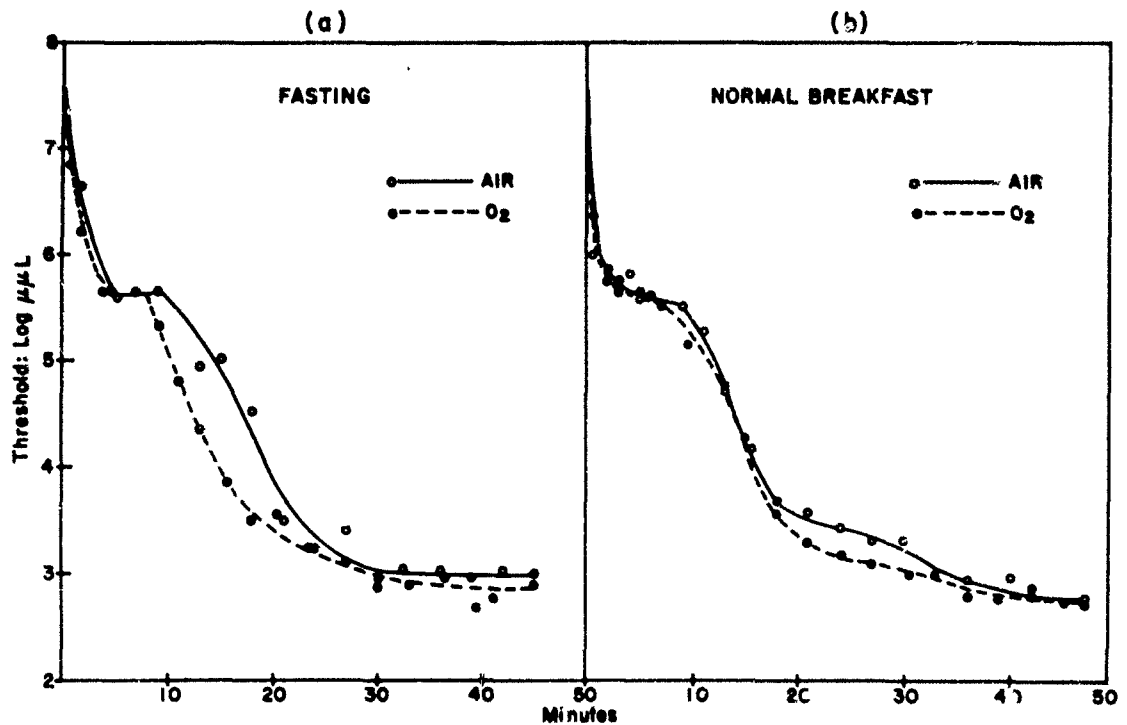


Figure 5. - Dark Adaptation Curves for Air (Compressed) and Oxygen: (a) After Fasting; and (b) After a Normal Breakfast. (Tests made on same subject on successive days)

DISCUSSION

These experiments were undertaken on the premise that dark adaptation thresholds would serve as a sensitive psychophysiological indicator of the incipient effects of oxygen excess. Since other physiological stresses have been found to affect dark adaption similarly, the goal became one of limiting the experimental parameters to oxygen concentration, pressure and period of administration. Practice effects were considered to be minimal. Pupil size variations were found to be negligible. No subject evidenced apprehension during the experiments. Other variables such as fatigue, boredom, and unobserved changes in blood sugar levels may have affected the results unpredictably.

Small changes in night vision thresholds, of the order of magnitude recorded in this study, do not have a great effect upon night vision per se. Small changes are important only insofar as they may reveal a physiological response to an experimentally induced stress.

One of six subjects showed an elevated rod threshold after breathing oxygen at one atmosphere for less than 20 minutes, indicating that this individual may have had a peculiar susceptibility to oxygen. At 2.82 atmospheres two of four subjects were affected similarly after breathing oxygen for 16 to 20 minutes. If the stress had been increased by further elevation of the pressure or extension of the period of oxygen inhalation it is reasonable to assume that an even higher percentage

would have shown threshold elevation. This is an area that needs further exploration.

The relationship between blood sugar levels and scotopic thresholds is well known. It was demonstrated in this investigation while the subjects were breathing oxygen. Mean blood sugar level of the three subjects used in the oxygen-glucose experiment ranged from 80 mg% in the basal state to 141 mg% one hour after glucose ingestion. During the same period the mean rod threshold ranged down to 0.25 log units lower. The individual thresholds reached a level indicating maximum effect of the glucose within fifteen minutes of ingestion.

The indication that breathing through a respiratory mask-demand valve system may depress the visual sense, apart from the effects of the inhalant, is of both theoretical and practical interest. Mullinax and Beischer (18) made the important point that psychological factors, carbon dioxide build-up, mask discomfort, water vapor and gas impurities may have only a nuisance value in obscuring the physiological effects of oxygen in an experiment, but are exceedingly important in considerations of oxygen utilization. It is not known whether the small mask-related decrement in the visual functioning of some subjects was the result of physiological stress or of a psychological factor such as lowered attention. Since interference with normal respiration was, perhaps, the most obvious physiological stress, an attempt was made to measure one of its aspects with a water manometer. Two subjects were tested while equipped with the same masks and demand valves that were used in the previously described experiments. The inspiratory resistance of the demand valve produced a mean pressure difference of 1.5 cm. of water during normal breathing for both subjects. It has not been established that artificial resistance to

breathing causes a change in night vision thresholds, but the subject merits further investigation. It would be particularly desirable to know whether tolerance to oxygen is affected by inhaling it through a mask-demand valve system.

The rapid transient threshold changes that usually occurred upon reverting from oxygen to air at the conclusion of the experiments performed at both sea level and elevated pressures may also be worthy of more critical study. In particular, it would be useful to determine if these perturbations may be sub-clinically related to the appearance, or exacerbation, of clinical signs of oxygen excess upon reverting from oxygen to air, as reported by Donald (19).

CONCLUSIONS

1. The effect of oxygen excess upon rod and cone scotopic thresholds is subject to individual variation.
2. Rod and cone scotopic thresholds are only exceptionally affected by breathing near-100% oxygen for periods to 140 minutes. When administered at higher pressures, even for periods as short as 20 minutes, the incidence of effects is sharply higher.
3. Rod and cone scotopic thresholds, measured while breathing near-100% oxygen, are sensitive to blood sugar levels.
4. Breathing through a mask-demand valve system of the type used in these experiments may cause an elevation of the rod and/or cone scotopic threshold(s) of some individuals, apart from any effect of the inhalant.

ACKNOWLEDGEMENTS

Several staff members rendered valuable assistance in this study. The alveolar oxygen monitoring system and the respiration study apparatus were set up under the direction of K. E. Schaefer, M.D.. Captain W. F. Mazzone, MSC, USN, set up the protocol for, and actively engaged in several of the experiments conducted in the decompression chamber. R. Hester, Ph.D., made valuable contributions to the treatment of the data. Thanks are also due the subjects, all of whom were volunteers, and to R. R. Lavole, HMC, USN, who stood the safety watch in the decompression chamber during pressure runs.

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13. ABSTRACT <p>Two series of experiments were conducted, --one was concerned with the effects of mask breathing, and the other with breathing 100% oxygen at ambient (sea level) pressure. It was found that the effect of oxygen excess upon rod and cone scotopic threshold is subject to individual variation. Rod and cone scotopic thresholds are only exceptionally affected by breathing near-100% oxygen for periods up to 140 minutes. When administered at higher pressures, even for periods as short as 20 minutes, the incidence of effects is sharply higher. Rod and cone scotopic thresholds, measured while breathing near-100% oxygen are sensitive to blood sugar levels. Breathing through a mask-demand valve system of the type used in these experiments may cause an elevation of the rod and/or cone scotopic threshold(s) of some individuals, apart from any effect of the inhalant.</p>		

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Scotopic sensitivity as affected by mask breathing Effect of breathing 100% oxygen on night vision							

INSTRUCTIONS

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